Appendix 10

Super conducting Wiggler Beam lines

Introduction

Super conducting wiggler magnets represent a special class of synchrotron radiation beam lines. The X-17 beam line is the only line utilizing a super-conducting wiggler at the NSLS and has operated successfully since the late 1980s. Any future magnet of this type will be subject to analyses similar to those described in this appendix. The essential parameters of the X17 super conducting wiggler magnet and its spectrum are given in figure 1.

There are two primary features which distinguish the radiation from the super-conducting wiggler (SUW) from that of a bending magnet or other insertion devices discussed in previous sections of this document - the higher critical energy, and the large horizontal divergence of the high power radiation fan. The significantly higher critical energy of the spectrum due to the high magnetic field gives a much harder photon spectrum compared to that from an NSLS bending magnet (see figure 1). To adequately shield against the higher energy photons requires a significantly greater amount of lead and steel compared to other NSLS beam lines. In addition, the entire beam line from the tunnel saw-tooth to the experimental area is enclosed in a hutch like structure to provide additional shielding and to exclude close proximity to the beam line components.

Heat Loads

In addition to the high-energy spectrum, the wiggler produces a large total radiated power. It has 7 poles, two at half field and 5 at full field of up to 5 tesla. With a critical energy of 22.2 keV at 2.528 GeV ring energy, the total power radiated by the device at a ring current of 250 mA is about 13.2 kilowatts into a fan of 41 mradians. The power density that must be dealt with at full operating electron current at this energy is thus about 1.77 kW/mrad^2 or 1.77 kW/cm^2 at a distance of 10 meters from the source.

It is necessary to carry out an extensive finite-element analysis[1] of all beam line components interacting with the photon beam (e.g. apertures, windows, masks, stops) in order to arrive at a final design.

Equipment Protection Interlocks

The increased power in the photon beams requires a more complex interlock system than other beam lines to prevent hardware damage from over-heating. The beam steering and monitoring of the electron beam have been designed to allow only those orbits that are safe for the machine hardware. As described below, magnet operation is interlocked with the physical positions of apertures and with the operating conditions of the storage ring in order to prevent accidental exposure of the vacuum vessels to extreme high thermal loading. In addition, the ring vacuum exit chambers were redesigned and replaced to allow passive safety against structural failures if targeted briefly by the direct photon beams. The enhanced design allows enough time for the sensing systems to dump the beam without severe damage resulting. The super conducting wiggler magnet bore tube has also been redesigned to allow passively safe operation.

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[1] “A Thermal Absorber for High Power Density Photon Beams”; S. Ulc and S. Sharma; Nuclear Instruments and Methods, **A246** (1986) 423-427

Because of the heat load in the wiggler beam, the front-end water-cooled mask and vacuum valves cannot be allowed to see wiggler radiation. Whenever the power supplies to the wiggler are on, the interlock system requires that the valve and mask be open. If the valves or mask close, the circulating beam is interlocked off. The safety shutters are designed to absorb the full heat load of the photon beam.

Radiation Shielding Requirements

The much harder photon spectrum produced by the high magnetic field of the SUW requires more extensive shielding. The beam line shielding program PHOTON was used extensively in 1988 to calculate radiation levels at all scattering points along the X17 beam line from the SUW to the rear of the last experimental hutch. These calculations determined the increased shielding necessary for this beam line.

An additional 1/8" of lead sheet shielding was added around the ring chamber and all front end elements in order to reduce levels outside the shield wall to as low as reasonably achievable.
The entire beam line downstream of the sawtooth is enclosed in a series of panels made of a composite of 1/8” steel + ¼” lead + 1/8” steel. These panels are assembled as a transport hutch from the sawtooth downstream to the beam line apertures and as hutches for the X17 experimental areas. Personnel are excluded from being in these enclosures via procedure and interlocks when the beam line is operational.

As examples, results of the initial PHOTON calculations are presented in Fig. 2 to 5. When the machine energy was upgraded to 2.8 GeV, additional shielding was provided as determined via operational surveys to maintain radiation dose rates to 50 μR/hr or less where possible. PHOTON was also used when the experimental hutches were re-built in 2002-3 to ensure that adequate shielding was provided for the new hutches.

Essential Parameters of X17 SUW

Device Parameters

Pole - full field	5
- half field	2
Period length	17.4 cm
Gap	3.2 cm
Magnetic field	5.22 Tesla

Operational Parameters

Maximum wiggler field	5.22	Tesla
Ring energy	2.528	GeV
Min. bending radius	1.615	meters
Critical energy (Ec)	22.2	keV
Deflection parameter K	84.47	
Horizontal opening angle on-axis	41.0	mradians
Vertically integrated power density	2.14	W/mrad-mA
Total power	52.8	W/mA

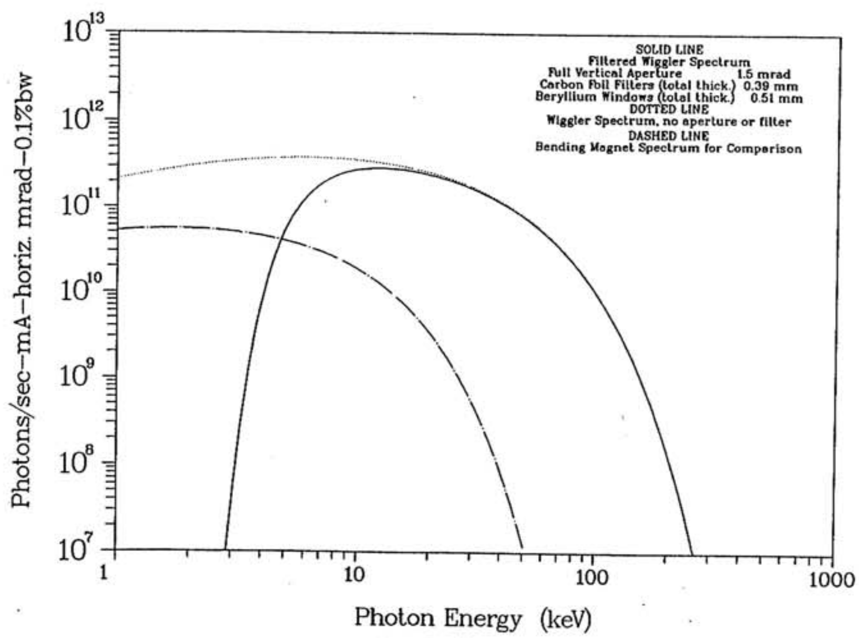

Figure 1
Essential Parameters for X-17 Superconducting Wiggler

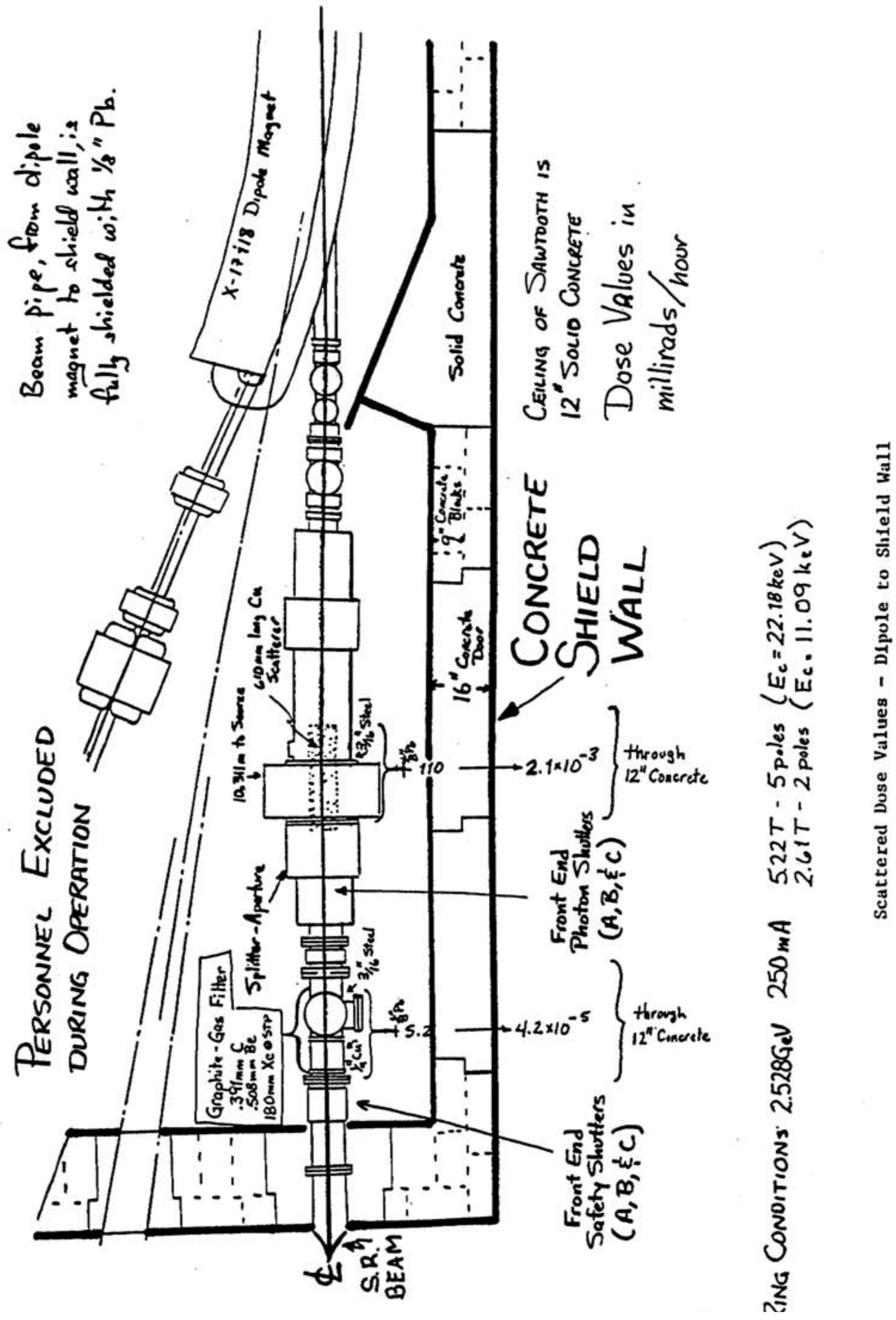

Figure 2

Calculated X-17 Radiation Levels from Scatter within X-ray Ring

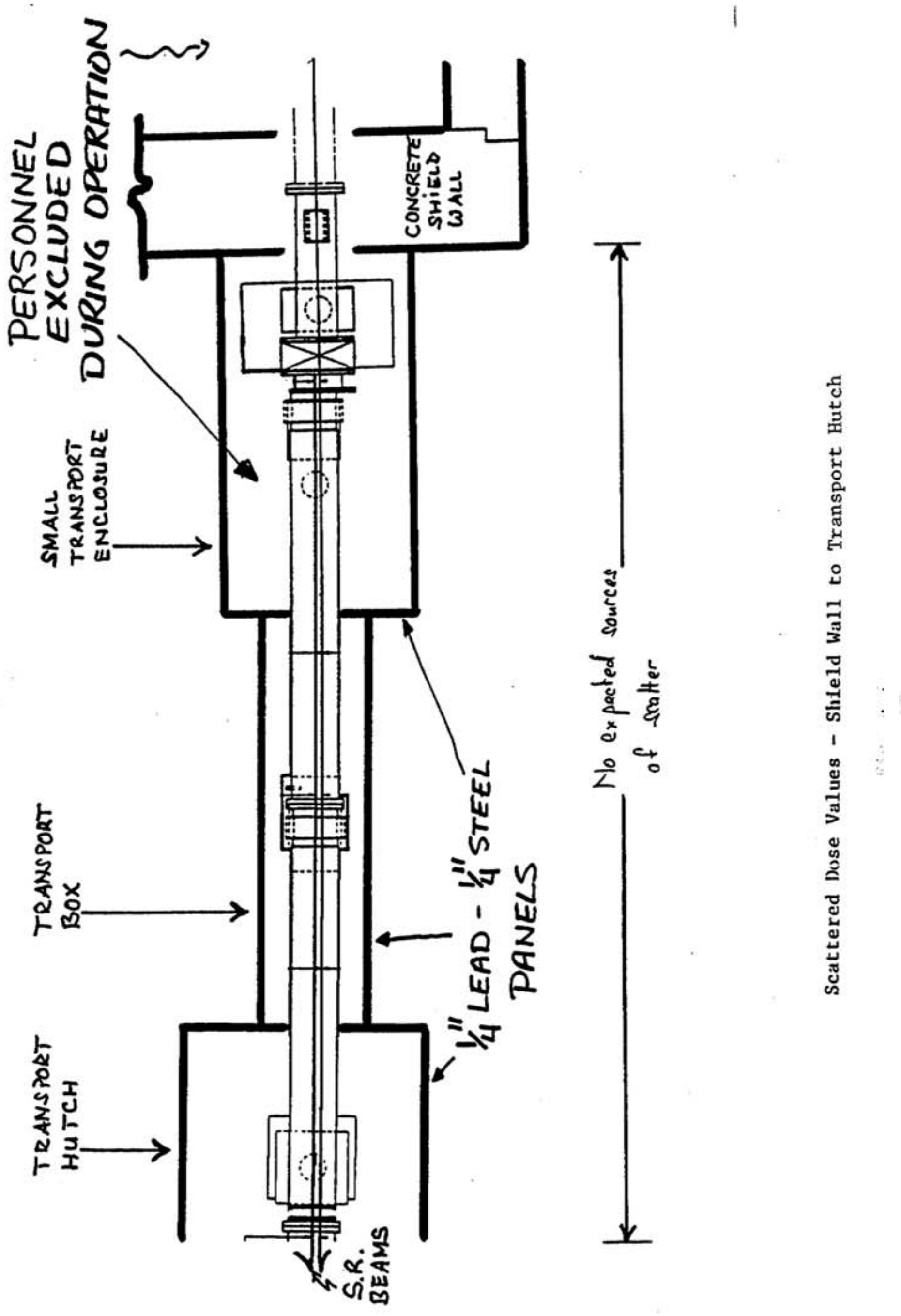

Figure 3

Calculated X-17 Scattered Radiation Levels in Upper Transport Line

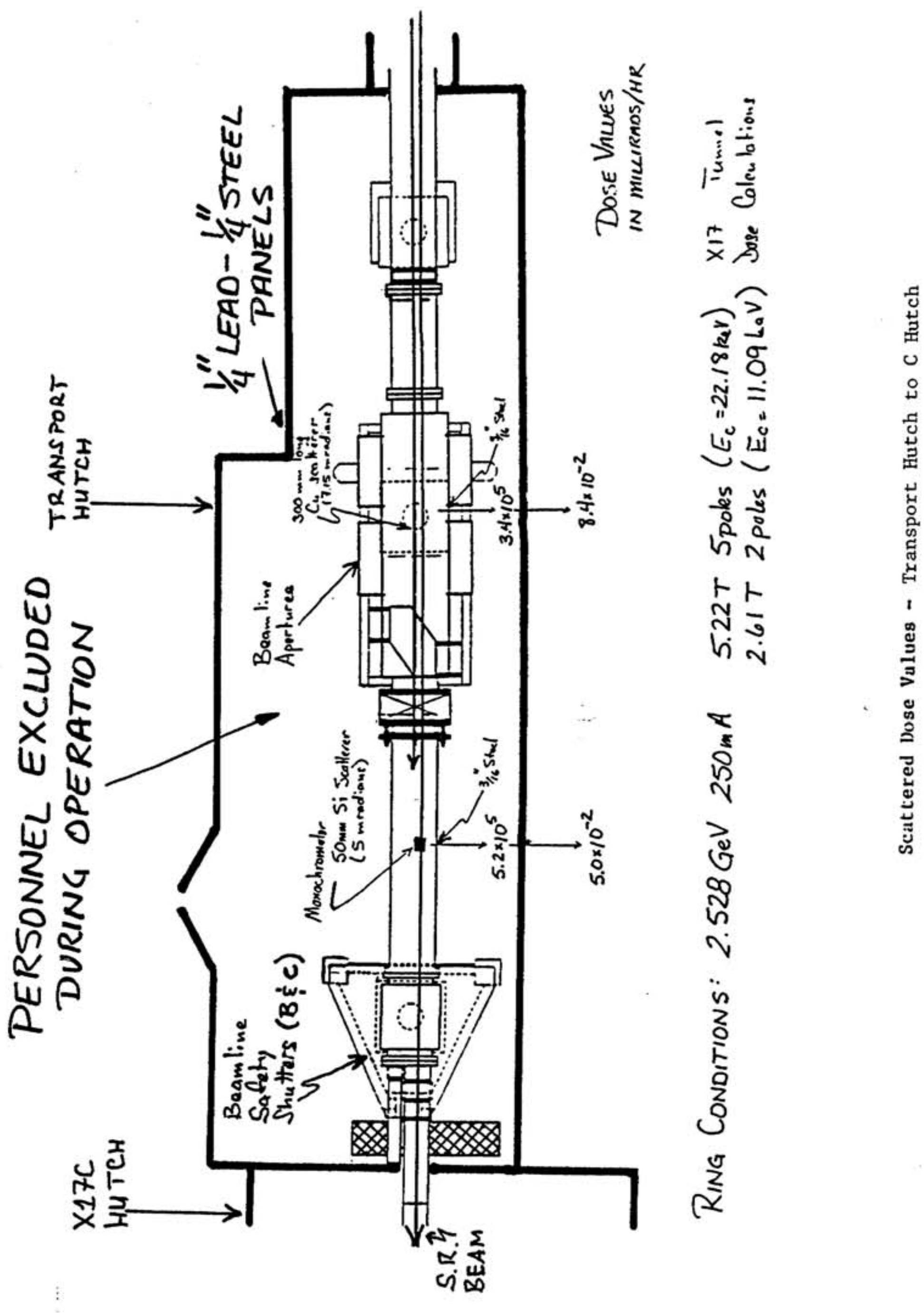

Figure 4

Calculated X-17 Scattered Radiation Levels in Lower Transport Line

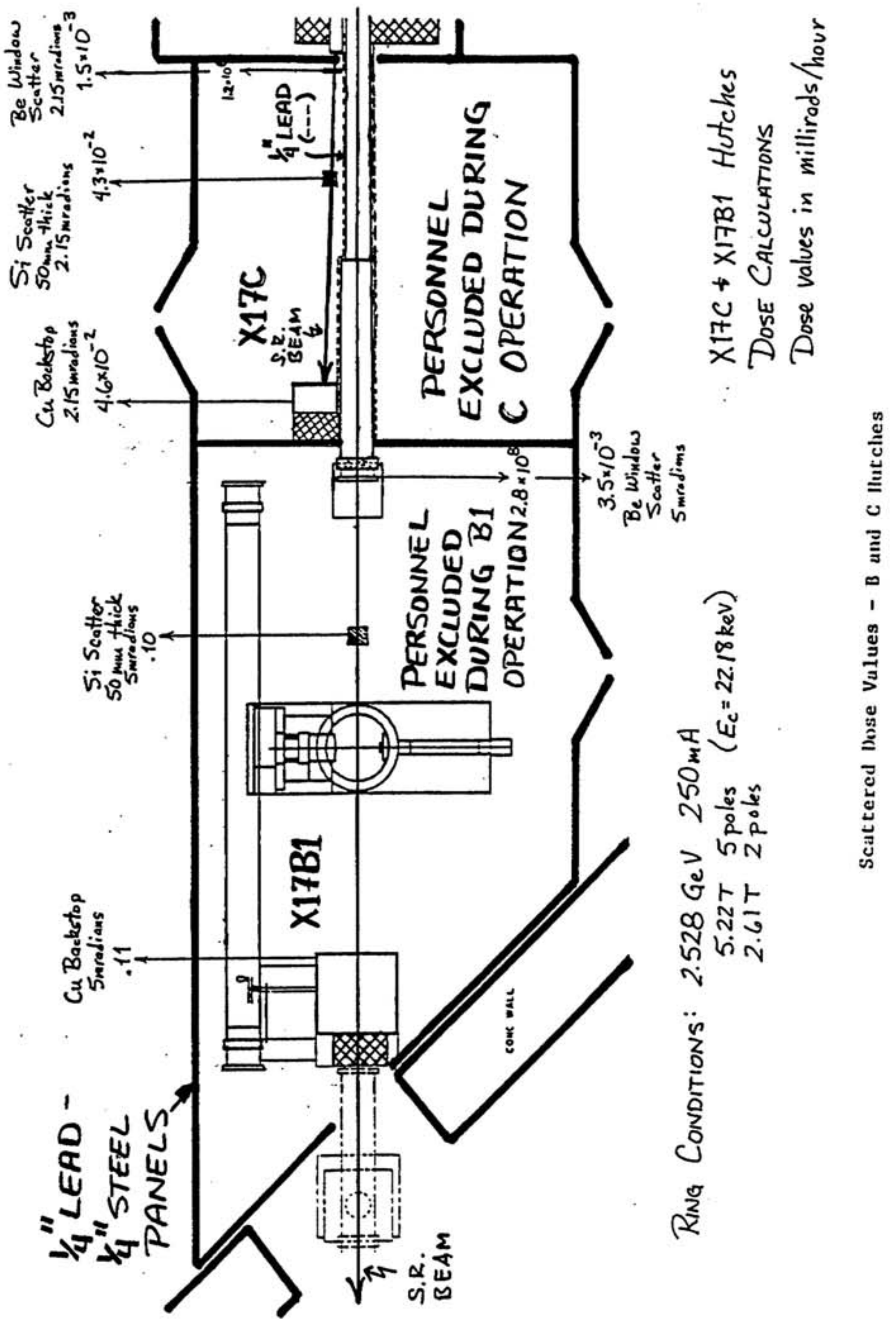

Figure 5

Calculated X-17 Scattered Radiation Levels from Experimental Hutch